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# MAGNETIC STRATIGRAPHY OF THE MIDDLE TO UPPER EOCENE SECTION AT BEAVER DIVIDE, FREMONT COUNTY, CENTRAL WYOMING

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**Abstract**—The Tertiary section at Beaver Divide, near Wagon Bed Spring, in Fremont County, Wyoming, was controversial for a long time because of the apparent mixture of Uintan and Chadronian fossil mammals. Emry (1975) clarified the stratigraphy of the Beaver Divide section, and showed that the apparent co-existence of Uintan and Chadronian fossils (suggesting a Duchesnean age to Scott, 1945) was due to confusion of specimens from the early Uintan Wagon Bed Formation, late Uintan Wiggins agglomerate, and the disconformably overlying earliest Chadronian Big Sand Draw Sandstone Lentil. Paleomagnetic samples were collected from the Beaver Divide section just north of Wagon Bed Spring. Samples were demagnetized with both alternating field and thermal demagnetization, and yielded a stable remanence held mainly in magnetite, with some minor overprinting due to goethite. After cleaning, the normal and reversed directions passed a reversal test, so the remanence is primary. The upper Wagon Bed Formation is entirely reversed in polarity. Based on its early Uintan (Uinta B equivalent mammals), we correlate it with Chron C20r (43.8-46.2 Ma). The late Uintan Wiggins agglomerate did not yield suitable paleomagnetic samples. The earliest Chadronian Big Sand Draw Sandstone Lentil is normal at the base, and reversed at the top. Based on its mammalian fauna (including the type specimen of the entelodont *Brachyhyops wyomingensis*, and several brontotheres, including *Duchesneodus primitivum*), we correlate it with Chron C17n-C16r (36.4-36.8 Ma). The remaining White River section is almost entirely reversed in polarity. Based on its middle Chadronian mammals, we correlate it with Chrons C13r-C15r (34.0-35.3 Ma). Thus, contrary to earlier notions that the section is relatively continuous, we interpret these results to mean that there are four short sequences at Beaver Divide separated by large disconformities.

**Keywords:** Eocene, Wyoming, Beaver Divide, Uinta, Duchesnean, Chadronian

## INTRODUCTION

Granger (1910) and Sinclair and Granger (1911) first described the stratigraphy and fossils from the Beaver Divide section near Wagon Bed Spring in Fremont County, Wyoming (Fig. 1). They recognized that the lower part of the section was equivalent to the Uinta Formation in Utah, but that the upper part of the section yielded brontotheres and thus was a White River equivalent. Between the two units was a conglomerate that also yielded brontotheres, so it was assumed to be at the base of the White River sequence. At that time, the "*Titanotherium* beds" were considered Oligocene (Wood et al., 1941), but the Chadronian land-mammal "age" has since been shown to be late Eocene, and the Uintan is late middle Eocene (Swisher and Prothero, 1990; Prothero and Swisher, 1992; Prothero and Emry, 1996). Colbert (1938) described the type specimen of the primitive entelodont *Brachyhyops wyomingensis* from the Beaver Divide area, but thought that it came from the upper Uintan beds. Scott (1945) mentioned protoreodont specimens from the conglomerate, and decided that this indicated that the conglomerate was Duchesnean in age, based on the apparent mixture of Chadronian brontotheres and Uintan protoreodonts. Van Houten (1964) recognized that there was a unit he named the Big Sand Draw Sandstone Lentil, which lay beneath the basal White River conglomerate, and recognized that there were two different facies in the conglomerate.

Emry (1975) restudied the stratigraphy and collected many additional fossils at Beaver Divide. His mapping and analysis showed that the controversial conglomerate was actually two units: a late Uintan volcanic agglomerate of the Wiggins Formation, unconformably overlain by the earliest Chadronian Big Sand Draw Sandstone Lentil, and then by another conglomerate (the "Beaver Divide Conglomerate" as restricted by Emry, 1975) that is part of the White River sequence (Fig. 2). Thus, the section is cut by several unconformities, one at the base of the Wiggins conglomerate, one at the base of the Big Sand Draw Sand-

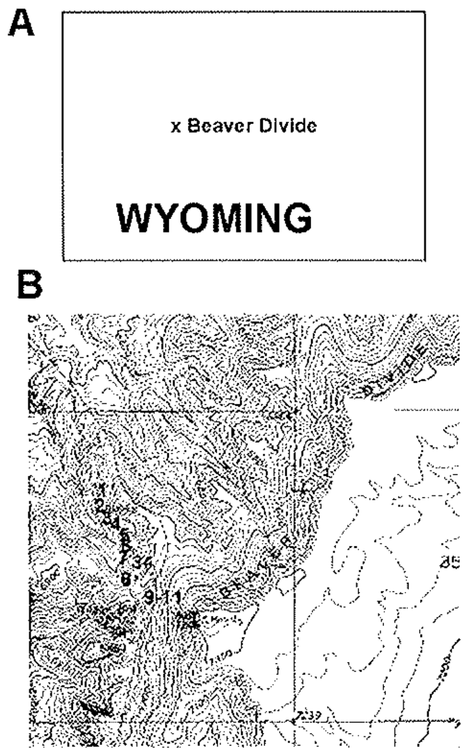


FIGURE 1. A, Index map showing location of Beaver Divide in Wyoming. B. Detail of the Dishpan Butte 7.5-minute quadrangle, showing the location of the Beaver Divide paleomagnetic sample sites (bold numbers 1-11) along Wyoming State Highway 135 through the center of sec. 34 T32N R95W, Fremont County, Wyoming. Each section is one mile (1.6 km) square on the side.

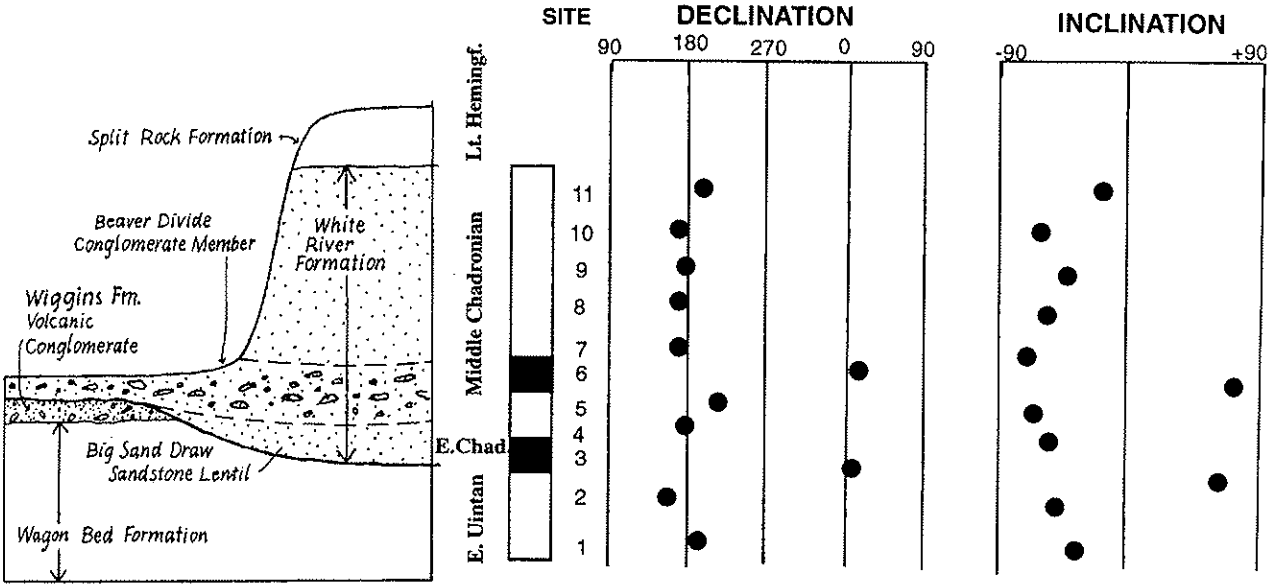


FIGURE 2. Lithostratigraphy and magnetic stratigraphy of the Beaver Divide section. Lithostratigraphy and biostratigraphy after Emry (1975). Declination and inclination of magnetic sites are shown. Solid circles are sites that are statistically removed from a random distribution at the 95% confidence level (Class I sites of Opdyke et al., 1977).

stone Lentil, and possibly another at the base of the Beaver Divide Conglomerate. Because of this complex stratigraphy, many of the original locality data on the specimens were confused, leading Scott (1945) to think that the Duchesnean was represented. Recent recollecting has shown that the section actually has four superposed faunas of Uintan and Chadronian age. These include:

1. The fauna of the upper Wagon Bed Formation, which includes *Amynodon advenus* and *Protoreodon parvus*, and is thought to be early Uintan (Uinta B equivalent) in age (Van Houten, 1964; Emry, 1975).

2. The fauna of the Wiggins agglomerate, which includes *Hyopsodus uintensis*, *Protoreodon pumilus*, and *Leptotragulus clarki*, and is thought to be late Uintan in age (Emry, 1975).

3. The fauna of the earliest Chadronian Big Sand Draw Sandstone Lentil. These include the type specimen of *Brachyhyops wyomingensis*, the brontotheres *Duchesneodus primitivum* and *Megacerops* sp., plus the ruminant *Leptomeryx* sp., the horse *Mesohippus* sp., and the rhinocerotoids *Metamynodon* sp., and *Hyracodon* sp. (Lucas et al., this volume).

4. The fauna of the remaining White River section, which yields a middle Chadronian assemblage (Van Houten, 1964; Emry, 1975; Emry et al., 1987).

Since the work of Emry (1975), additional specimens have been documented (Lucas et al., this volume), and the Uintan, Duchesnean, and Chadronian have been more precisely calibrated by means of magnetic stratigraphy and argon/argon dating (Prothero and Emry, 1996). Thus, it is now possible to take magnetic samples on a short, discontinuous section like Beaver Divide and arrive at reasonable magnetostratigraphic correlations based on the calibration from fossil mammals.

## METHODS

Sampling was conducted in the spring of 2003 along the road cuts of Wyoming State Highway 135 (Fig. 1), and along the bluffs to the east of Wagon Bed Spring. The section was located in the SE 1/4 NW 1/4 to the NE 1/4 SW 1/4 sec. 34, T32N R95W, Dishpan Butte 7.5-minute quadrangle, Fremont County, Wyoming. Each sample was taken with simple hand tools by scraping a horizontally-oriented surface at the top of the block of rock. In the laboratory, the block samples were cored with a drill press, or molded into disks of Zircar aluminum ceramic if they were too small or crumbly to withstand the drilling. The core samples were then measured on a 2G cryogenic magnetometer with an automatic sample changer at Caltech. After measurement of NRM (natural remanent magnetization), all samples were demagnetized in alternating fields (AF) of 25, 50, and 100 Gauss to remove any remanence caused by multi-domain grains before it is baked into the sample, and to determine the coercivity behavior of each sample. After AF demagnetization, each sample was then thermally demagnetized in 50° steps from 200°C to 630°C to remove chemical overprints due to goethite, and to see how the remanence behaved as the components were removed and the temperatures approached and exceeded the Curie points of magnetite (580°C) and hematite (630°C).

Results were plotted on orthogonal demagnetization ("Zijderveld") plots, and average directions of each sample were determined by the least-squares method of Kirschvink (1980). Mean directions for each sample were then analyzed using Fisher (1953) statistics, and classified according to the scheme of Opdyke et al. (1977).

## RESULTS

Representative orthogonal demagnetization plots are shown in Figure 3. In Figure 3A, the sample exhibits normal polarity at NRM (the direction is north and down), and the rapid decline in intensity through AF demagnetization shows that the remanence is held in a low-coercivity mineral, such as magnetite. In Figure 3B, a typical reversed sample shows a single component of remanence, which is reversed (south and up) at NRM and decays steadily to the origin, losing all remanence as it exceeds the Curie point of magnetite (580°C). This

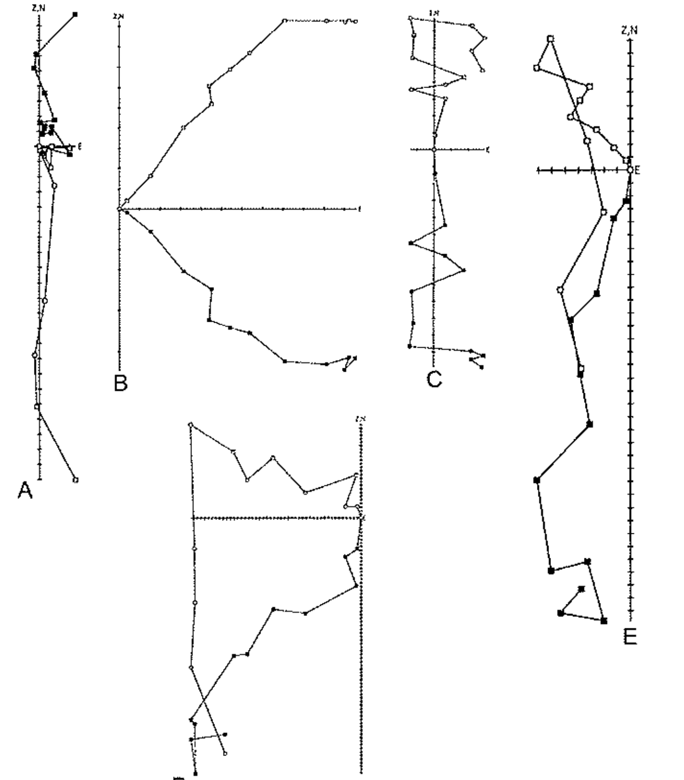


FIGURE 3. Orthogonal demagnetization ("Zijderveld") plots of representative samples. Solid squares indicate declination (horizontal component); open squares indicate inclination (vertical component). First step is NRM, followed by AF steps of 25, 50, and 100 Gauss, then thermal steps from 200° to 630°C in 50°C increments. Each division equals $10^{-5}$ emu.

sample apparently has a high-coercivity overprint of goethite, judging from the slight decline in intensity in the first three AF demagnetization steps. In Figure 3C, the sample is also reversed at NRM, but decayed steadily to the origin, and lost all remanence by 600°C; this, and the fact that there was a significant low-coercivity component, suggests that the remanence was carried by magnetite. In Figure 3D, the sample showed a slight normal overprint (at NRM it pointed south and down), but by 200°C, the overprint has been removed, and the sample decreases in intensity steadily toward the origin. The remanence in this sample is carried only by magnetite, because it loses all remanence by 600°C, and because it has a low coercivity. In Figure 3E, the sample also showed a normal overprint (it was south and down at NRM), but it was removed by 100 Gauss, and the sample decreased in intensity steadily toward the origin. The low coercivity and the loss of all remanence by 600°C is also consistent with magnetite as the carrier of remanence is this sample.

TABLE 1. Paleomagnetic data from the Beaver Divide section

| SITE | DEC | INC | K | $\alpha_{95}$ |
|---|---|---|---|---|
| 1 | 197.5 | -29.5 | 28.7 | 23.4 |
| 2 | 165.7 | -39.5 | 15.2 | 32.7 |
| 3 | 5.6 | 68.6 | 142.0 | 10.4 |
| 4 | 181.0 | -48.2 | 7.8 | 47.6 |
| 5 | 220.9 | -57.8 | 67.6 | 15.1 |
| 6 | 14.2 | 75.2 | 62.5 | 15.7 |
| 7 | 174.7 | -59.9 | 24.2 | 25.6 |
| 8 | 177.0 | -48.7 | 15.5 | 32.4 |
| 9 | 182.2 | -21.6 | 67.5 | 15.1 |
| 10 | 180.5 | -62.8 | 17.4 | 30.5 |
| 11 | 197.4 | -13.4 | 13.0 | 35.7 |

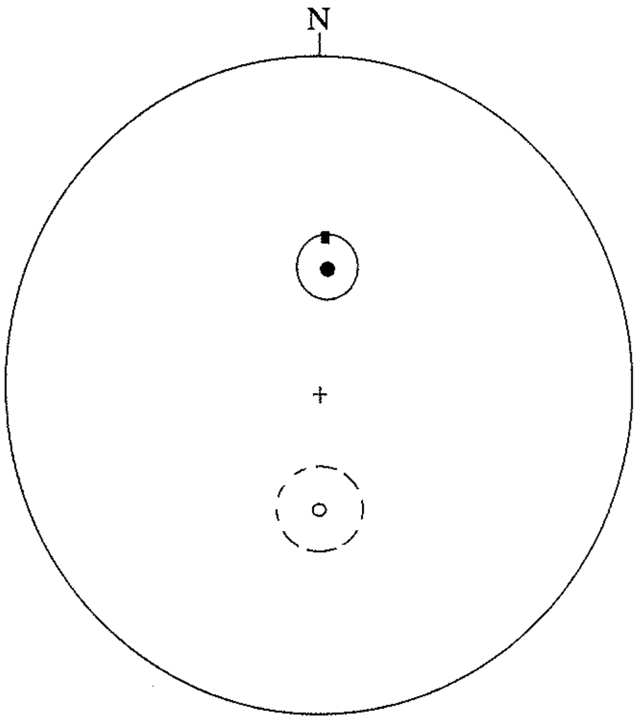


FIGURE 4. Stereonet of mean of normal and reversed sites. Solid circle and lines indicate mean and ellipse of confidence of normal samples (lower hemisphere projection); open circle and dashed line indicate mean of reversed samples (upper hemisphere projection). Solid square indicates projection of reversed mean to the lower hemisphere of the stereonet.

Mean directions for all sites are given in Table 1. As can be seen in Figure 2, all but two of the 11 sites were reversed in polarity, and all of the sites were statistically significant at the 95% confidence level (Class I sites of Opdyke et al., 1977).

The mean direction for the two normal sites was D = 9.2, I = 52.0, k = 86.9, $\alpha_{95}$ = 7.2 (n = 6). The mean direction for the 9 reversed sites was D = 186.4, I = -43.4, k = 15.3, $\alpha_{95}$ = 13.6. As can be seen from a stereonet plot (Fig. 4), the mean directions are antipodal within error estimates, so the directions pass a reversal test. The overprints have been removed, and the resulting vectors represent the primary or characteristic remanence in the samples.

## DISCUSSION

Correlation of the Beaver Divide paleomagnetic results is shown in Figure 5. The two sites in the uppermost Wagon Bed Formation are of reversed polarity. Based on the early Uintan mammals recovered from the upper Wagon Bed Formation in this area (Emry, 1975), we correlate this section with Chron C20r (43.8-46.2 Ma), since this is the only long reversed interval in the early Uintan (Prothero and Emry, 1996). Evernden et al. (1964) reported a K-Ar date of 45.4 Ma in the middle part of the Wagon Bed Formation near Wagon Bed Spring (corrected to 46.6 Ma, using the decay constants of Steiger and Jager, 1977). This date also falls within Chron C20r (Fig. 5), consistent with our interpretation.

We attempted to sample the volcanic agglomerate of the Wiggins Formation, but without success. Thus, its magnetic polarity is unknown.

The tan sandstones of the Big Sand Draw Sandstone Lentil can be clearly seen incised into the greenish mudstones of the Wagon Bed Formation, and were normal in polarity at the base, but reversed at the

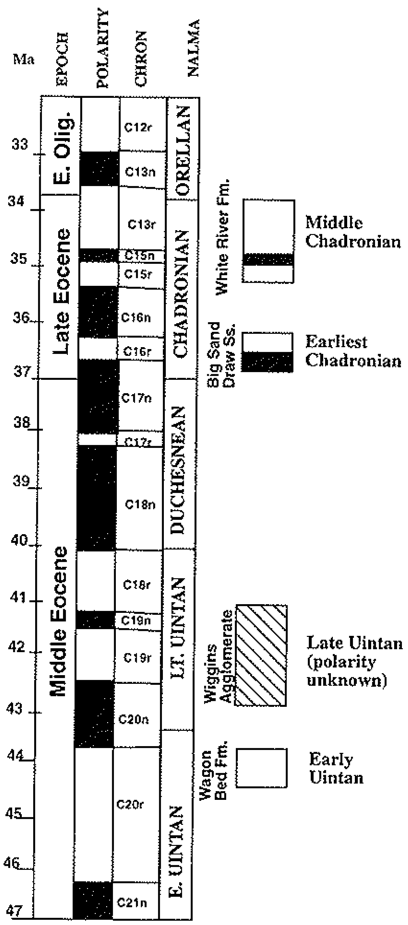


FIGURE 5. Correlation of the Beaver Divide paleomagnetic section, based on the age constraints discussed in the text. Time scale after Berggren et al. (1995), Prothero and Emry (1996), and Prothero and Swisher (1992).

top. Based on the presence of *Brachyhyops wyomingensis* (which only occurs elsewhere in rocks correlated with Chrons C16n2-C16r, and older, according to Prothero and Emry, 1996, fig. 3) and other earliest Chadronian taxa, we correlate this normal-reversed pattern with Chrons C17n-C16r (36.4-36.8 Ma).

The remaining 100 m of White River Formation, starting with the Beaver Divide Conglomerate (*sensu* Emry, 1975), is mostly of reversed polarity except for a single normal site in the upper part of the conglomerate. Based on the middle Chadronian mammals reported by Van Houten (1964), Emry (1975) and Emry et al. (1987), we correlate it with Chrons C13r-C15r (34.0-35.3 Ma). This is consistent with the biostratigraphic and magnetostratigraphic interpretations of the Flagstaff Rim section in Natrona County, Wyoming, east of Beaver Divide (Prothero and Emry, 1996).

## CONCLUSIONS

The stratigraphy of the Beaver Divide section has long been confused, but recent work shows that it contains four superposed faunas, which can be magnetostratigraphically correlated. These include the early Uintan Wagon Bed Formation (correlated with Chron C20r, or 43.8-46.2 Ma), the late Uintan Wiggins agglomerate (not sampled in this study), the earliest Chadronian Big Sand Draw Sandstone Lentil (correlated with Chrons C17n-C16r, or 36.4-36.8 Ma), and the middle Chadronian Beaver Divide Conglomerate and White River Formation (correlated with Chrons C13r-C15r, or 34.0-35.3 Ma). Thus, instead of a continuous Uintan-Duchesnean-Chadronian sequence as suggested by earlier workers, the Beaver Divide section is actually composed of four short sequences bounded by large unconformities.

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